

Energy Efficient Labs and Cleanrooms for High Tech Industry

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Commission), annually awards up to \$62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research.

What follows is the final report for the Energy Efficient Labs and Cleanrooms for High Tech Industry Project, Contract #400-00-020, conducted by the Lawrence Berkeley National Laboratory. The report is entitled *Energy Efficient Labs and Cleanrooms for High Tech Industry*. This project contributes to the PIER Industrial/Agricultural/Water End-Use Energy Efficiency Program.

For more information on the PIER Program, please visit the Commission's Web site at: <http://www.energy.ca.gov/research/index.html> or contact the Commission's Publications Unit at 916-654-5200.

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Appendix IV. “Design Intent Tool Website”

Berkeley Fume Hood Appendices:

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High-Performance Laboratories and Cleanrooms – a Technology Roadmap

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Executive Summary

Laboratories and cleanrooms are an integral part of California's high-technology industries--prevalent in both public and private sector buildings serving semi-conductor, electronics, bio-pharmaceutical, and many other growing sectors of the economy. The facilities for all of these industries have one thing in common—they are extremely energy intensive.

Recognizing the importance of improving energy efficiency in California's high-tech industries, and that further research was needed to reach a goal of a 40-50% improvement in efficiency, the Commission requested LBNL to develop an agenda for public interest research for energy efficiency in laboratories and cleanrooms and to advance the knowledge of efficiency opportunities in laboratories and cleanrooms.

Background

Prior Public Interest Energy Research (PIER) funded work has led to the development of new technologies, tools, and strategies, which will make a significant difference in the overall efficiency of high-tech buildings. This project continued research for a limited number of tasks that showed promise ("no regrets") based upon the work performed in the previous PIER High-tech buildings project. PIER support for this work was required because no private or public sector programs are supporting comprehensive energy efficiency research in this area.

Objectives

This project's overall objective was to advance the knowledge of efficiency opportunities in laboratories and cleanrooms, eventually leading to a 50% reduction in energy consumption. Specific objectives were as follows:

1. To provide guidance to cleanroom owners, designers, and operators concerning issues frequently decided early in a project – at the planning (Programming) stage, often causing irreversible, adverse, energy implications.
2. To develop a database tool for laboratory owners, designers, and operators use to capture the original design intention and easily keep track of changes and performance during the life cycle of the laboratory.
3. To support continued development of the Berkeley high performance Fume Hood by performing research required for demonstration projects (funded by others) at two university laboratories, identify needed improvements, and provide a commercialization plan. Future direction based upon lessons learned from the demonstrations was to be identified. As a result of, and following completion of this task, additional scope was added to the contract with the objective of developing a larger, six-foot hood and demonstrating the high performance hood in industrial settings.
4. To work with industry to identify and prioritize the research, development, and deployment necessary to achieve a 50% reduction in energy for laboratories and cleanrooms through a multi-year program

Outcomes

Specific outcomes of this research included the following:

1. The publication of a Cleanroom Programming Guide

2. The development of a Laboratory Design Intent Tool
3. The demonstration of the Berkeley High Performance Hood.
4. The development of a High-tech Buildings Energy Roadmap.

Conclusions, Recommendations, and Benefits to California

Cleanroom Programming Guide:

- Industry feedback was positive and expressed the need for more guidance and ideas on methods to improve efficiency of cleanrooms.
- Trial use of the Programming Guide is necessary to determine how it will be used and to identify enhancements to ensure its use.
- The guide provides a needed resource to the high-tech community that is so important to California's economy. Although it is difficult to quantify savings potential - this will depend on the measures undertaken by the individual programming teams and overcoming barriers - prior investigations suggest that 10-20% savings can be readily obtained through better design.

Laboratory Design Intent Tool:

- The tool was considerably improved during this development phase, with extensive cross-linkages to the Laboratory Design Guide, and a new User Guide developed. Based upon initial market research and subsequent user feedback, there is clearly a desire to have the tool ported to a web-based platform so that it would function more effectively as a collaborative tool.
- The tool can be easily adapted to other building types providing a useful tool for design, commissioning, and operations of many types of facilities.

Berkeley High Performance Hood:

- The technology utilized in the Berkeley Fume Hood can provide significant energy savings along with improved worker safety. In California, the energy consumed by a standard fume hood is approximately equal to that of three houses. Saving up to 60% of this energy is a promising goal for the Berkeley hood.
- Follow-on development activities are proposed with the objective of resolving institutional barriers, completing scale-up and side by side testing of a six-foot hood, and demonstrations in industrial settings. Future development to establish side-by-side testing with a conventional fume hood, use of Computational Fluid Dynamics (CFD) analysis to aid design and verify performance, and demonstrations in three to five facilities in various industries. Future development to establish a retrofit design using the Berkeley Hood technology should also be pursued.
- Estimated savings in California through use of the Berkeley Hood are approximately \$162 million/year with a peak load saving of 215 MW.

High-tech Buildings Energy Roadmap:

- The California Energy crisis and the downturn in the high-tech sector have both led to increased interest in saving energy. As a result, the industry definitely supported the research efforts related to high tech buildings. Previous research and previously obtained benchmark results helped to focus discussion on the most energy intensive systems and their research opportunities/needs.

- A multi-year research agenda is presented in the roadmap. California's PIER program should proceed with the high priority tasks identified by industry as the most beneficial to California companies. Collaboration with other industry efforts, such as Sematech, ASHRAE, IEST, etc. should continue to maximize energy efficiency potential as identified in the roadmap. To achieve the full potential in energy savings, a whole building approach is needed.
- High-Tech industries are continually in change. Process technologies change rapidly and have a profound impact on high-tech facilities. Consequently, the roadmap topics and their priority should be reviewed periodically. The roadmap should be considered a living document with changes in priority and technological emphasis made as the market needs change.
- The High Performance Laboratories and Cleanrooms technology roadmap provides the PIER program with much needed understanding of industry views of needed research and its priority. The Commission's Industrial Program will be able to utilize the roadmap to plan a strategy to aggressively make improvements in this critical market sector. The roadmap will also facilitate collaborations with other energy research and industry organizations thereby leveraging California's efforts.
- A multi-year research agenda is presented in the roadmap. California's PIER program should proceed with the high priority tasks identified by industry as the most beneficial to California companies.

Abstract

Energy Intensive laboratories and cleanrooms (high-tech buildings) are crucial to California's high-technology industries. To help focus public goods research, the Commission's PIER Industrial Program decided to continue previous research in a few high potential areas, while developing a "roadmap" to guide future research and deployment.

Consequently, development of a Design Intent Tool for use in laboratories, and the high performance fume hood invented at LBNL, both of which were begun in the previous PIER project, were pursued.

The Design Intent Tool was developed into a Microsoft Access TM software tool for use in identifying the designer's original intentions and then tracking the design intent through commissioning and throughout the life of the laboratory.

Another task, involved further development of the high performance fume hood. This work involved adapting the technology to a larger 6-ft hood, working to get the technology accepted by Cal/OSHA, and was planned to include demonstrations at several industrial facilities. Although several industrial partners were eager to participate, the development and testing could not be completed as originally planned thereby delaying demonstrations to later phases.

An additional task, with cost share from the Northwest Energy Efficiency Alliance, was to develop a "Cleanroom Programming Guide" to assist cleanroom owners and operators to make energy efficient choices when starting new projects.

Finally, a research "roadmap" was developed through interaction with industry representatives involved in design and operation of high-tech buildings. This was developed through workshops, surveys, participation in industry associations, and collaboration with other research organizations.

The Design Intent Tool, Cleanroom Programming Guide, and the Research Roadmap were all completed and are available at the LBNL website. Likewise, detailed information on the status of the high-performance fume hood is available on the web.

1.0 Introduction

1.1. Background

Laboratories and cleanrooms are an integral part of California's high-technology industries. Laboratories and cleanrooms are prevalent in both public and private sector buildings serving semi-conductor, electronics, bio-pharmaceutical, and many other growing sectors of the economy. The facilities for all of these industries have one thing in common—they are extremely energy intensive. In the 1999 PIER report (Sartor, et.al.1999), LBNL estimated energy consumption of California's high-tech building sector at 9.4 billion kWh and 25 TBtu's of natural gas. LBNL's prior research, through case studies, workshops, design charrettes, surveys, and other targeted research, has shown that there are numerous opportunities for improving energy efficiency in these buildings. Cleanroom energy benchmarking has also highlighted the potential for significant energy savings.

Using a "whole buildings" view of the opportunities, a 40-50% reduction in facility energy use is possible. A targeted effort is required to achieve this level of energy savings. Numerous opportunities are apparent within the individual systems that support laboratory and cleanroom facility operations. Although this project focused on the building systems, additional savings are possible for the energy used in the processes occurring within the high-tech buildings.

Prior Public Interest Energy Research (PIER) funded work has led to the development of new technologies, tools, and strategies, which will make a significant difference in the overall efficiency opportunity. This project continued research for a limited number of tasks that showed promise ("no regrets") based upon the work performed in the previous PIER High-tech buildings project. PIER support for this work was required because no private or public sector programs are supporting comprehensive energy efficiency research in this area.

Recognizing the importance of improving energy efficiency in California's high-tech industries, and that further research was needed to reach a goal of a 40-50% improvement in efficiency, the Commission requested LBNL to develop an agenda for public interest research for energy efficiency in laboratories and cleanrooms. It was recognized that an integrated set of technologies and strategies would be needed to reach the overall goal. An outline of topics for an energy research and development roadmap was prepared by LBNL during the preceding PIER project based upon research, observations, and industry feedback. This became the starting point for development of the roadmap. As described in this report, additional industry input was obtained through workshops, surveys, industry associations, and our industrial partners.

1.2. Objectives

This project's overall objective was to advance the knowledge of efficiency opportunities in laboratories and cleanrooms, eventually leading to a 50% reduction in energy consumption. There were four distinct tasks in the project, each with its own objective, as described in Table 1.

Table 1. Project Tasks and Objectives

Project Task	Objective
Cleanroom Programming Guide	To provide guidance to cleanroom owners, designers, and operators concerning issues frequently decided early in a project – at the planning (Programming) stage, often causing irreversible, adverse, energy implications.
Laboratory Design Intent Tool	To develop a Microsoft Access TM tool for laboratory owners, designers, and operators use to capture the original design intention and easily keep track of changes and performance during the life cycle of the laboratory.
Berkeley High Performance Hood	To support research necessary for field tests at two university laboratories, identify needed improvements, and provide a commercialization plan. Future direction based upon lessons learned from the demonstrations funded by others was to be identified. As a result of, and following completion of this task, additional scope of work was added to the contract with the objective of scaling up to a six foot hood and demonstrating the high performance hood in industrial settings.
High-tech Buildings Energy Roadmap	To identify and prioritize the research, development, and deployment necessary to achieve a 50% reduction in energy for laboratories and cleanrooms through a multi-year program.

The High-tech buildings work has also been leveraged through support from other synergistic projects and collaboration:

- **Department of Energy (DOE)** - for research on the fume hood related to intellectual property rights, and for design assistance to Federal High Tech Buildings
- **Environmental Protection Agency (EPA) and DOE's Federal Energy Management Program (FEMP)** – through “Laboratories for the 21st Century”
- **Northwest Energy Efficiency Alliance (NEEA)** – for additional development of the Cleanroom Programming Guide

- **Public Utilities** – For cleanroom energy benchmarking and demonstrations of the Berkeley Fume Hood in University settings.
- **Industrial Partners** – Many Industrial partners provided materials and/or in-kind support - including fume hoods and controls, development of the Cleanroom Programming Guide, and input to the High-Tech buildings Energy Efficiency Roadmap.
- **Industry Associations** – Informal collaboration with Sematech, ASHRAE committees for Laboratories (fume hoods) and Cleanrooms, Institute of Environmental Sciences and Technology (IEST), and the Silicon Valley Manufacturers Group

1.3. Report Organization

This report addresses each of the four tasks. The Project Approach, Project Outcome, and Conclusions and Recommendations sections of the report each contain separate summaries of the respective tasks. A brief summary of the task activity is included, and the deliverables are attached as appendices. The appendices generally provide greater detail into the task, the findings, and recommendations.

2.0 Project Approach

2.1. Cleanroom Programming Guide

The Cleanroom Programming Guide was targeted for Cleanroom designers and Cleanroom owners/operators. Programming is a term used by building design professionals describing the initial phase of the design process. The programming process referred to here is described in the book titled “Problem Seeking: An Architectural Programming Primer,” by William Peña, et al. Programming should be the first step in the design process to identify facts, goals, concepts, and needs of the project resulting in a statement of the problem that the design team will solve. Considering energy implications prior to beginning the design allows the team to make informed decisions that support other key program requirements and achieve high operating efficiency. Decisions made at the programming phase will direct the design process.

The Guide was meant to provide a framework to highlight key issues for focus during the early stages of a project. This is important because their consideration can affect energy consumption over the life of the facility. Traditionally, decisions affecting a number of major design features are made during this phase for a variety of reasons such as scheduling pressures due to long lead-times, or availability of material. These decisions often have adverse energy implications. Additionally, the owner and design team may have preconceived preferences based on prior experience, company policy, or personal preferences. In many cases decisions have been made to satisfy other program goals with little consideration for long-term operational cost – including the cost of energy.

Programming of cleanroom facilities is a complex planning exercise dealing with hundreds of interrelated, and at times, conflicting goals and facts. Decisions have in many cases been dictated by first cost considerations without benefit of life cycle, or cost of ownership evaluations.

The approach in developing this guide generally involved four activities:

1. Cleanroom programs for past cleanroom projects were reviewed to see what was typically included for energy consideration. As expected, we found that there was little or no mention of energy in the programs reviewed and this confirmed the importance of preparing a guide.
2. Topics for the guide were initially developed from prior research and benchmarking. Energy efficient designs and concepts identified through charrettes and case studies helped highlight areas for consideration. Cleanroom energy benchmarking provided further insight into the energy intensive systems and also revealed huge potential for efficiency.
3. The guide topics were further developed through a workshop and interaction with leading designers, energy engineers, and cleanroom operators. Then a draft document was issued for comment.
4. The content of the programming guide was presented in workshops in the Northwest and in the San Francisco Bay Area. Additional feedback was obtained (such as including a checklist) and incorporated into the document. It was then issued for trial use.

2.2. Design Intent Tool

As the fields of facility design and management mature, there is an increasing understanding that it is necessary but not sufficient to simply specify “good” technologies or design features in order to achieve desired performance. Efforts to do so are often thwarted by the absence of explicit direction from the owner, misunderstandings and different visions among members of the design team, and ambiguities imposed by the lack of measurable performance targets. The lack of clarity created by these problems in turn hampers the post-construction commissioning and measurement & verification processes. A more comprehensive and holistic approach can be initiated with “Design Intent Documentation”. In the current world, buildings often fail to perform in practice as expected during design. In the case of energy-efficiency, actual savings often fall short of predictions. A building design process devoid of quantitative feedback does not detect or correct problems. One cause of this is the lack of a consistent method for documenting and communicating information about intended performance.

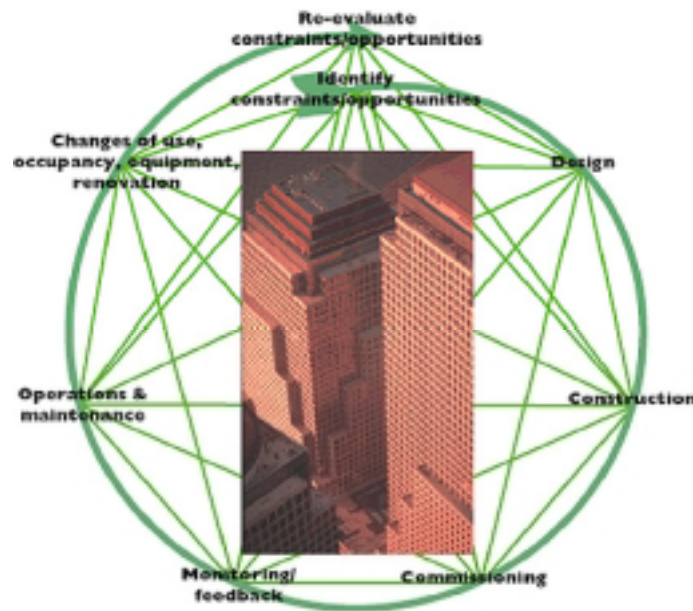


Figure 1. DIT

Design intent documentation, initiated at the earliest phases of the building lifecycle (Figure 1) can help ensure successful attainment of energy efficiency and other aspects of building performance.

At the heart of the Design Intent Tool is a framework in which design solutions can be described in terms of Objectives (overall goals), with subordinate Strategies (specific means of achieving the goals), and Metrics (measurable performance targets). The result is an improved likelihood of attaining desired energy efficiency targets. A Design Intent Document is intended to capture and preserve this information across the building's life-cycle, helping to ensure that

- Participants in the project are able to clearly document their desired performance objectives during initial planning phases.
- Evaluations of proposed design options are better supported and the resulting decisions (including rejection of preliminary recommendations) are better documented and shared among design team members.
- Assessment of design changes during construction and operations and maintenance (O&M) is improved.
- The commissioning process is more comprehensive and cost-effective when supported by access to clearly specified performance targets.
- O&M evaluation of the day-to-day performance of systems and the early detection and diagnosis of operational problems are enhanced through performance benchmarking.
- Performance contracting and measurement and verification are supported in a structured and proactive manner.
- Post-occupancy evaluation is more easily performed.

The project work scope was to make the following enhancements to the draft tool that was developed in the previous PIER project and develop it to operate in a Microsoft Access database:

1. Improve the user interface to ease usability
2. Add a user manual (“User Guide”) (see Appendix II)
3. Integrate the existing Laboratory Design Guide and the Laboratory Design Intent Tool. The final product enables the user to easily and simultaneously install both tools, ensuring their interoperability.
4. Develop quantitative database fields to facilitate graphical tracking of design intent relative to actual performance. This was accomplished by integrating “Metrics” and “Target Values” into the structure of the user-inputs and creating a “Data Tracker” report, exported into an Excel spreadsheet file format.
5. Test the tool in a complex laboratory project (see Appendix III)
6. Gather user feedback from the project participants/design team
7. Solicit input on the results of this test from other interested parties
8. Modify the tool based on user feedback
9. Post the tool on LBNL’s website

In addition to the contract work scope:

1. The tool is coupled with the Internet, so that the user can access supporting on-line resources. A special website was created to host the tool downloads, and provide ancillary information (see Appendix IV).
2. Templates were developed to provide users with “default” content applicable to (a) laboratory-type facilities and (b) LEED-compliant commercial buildings. Linkages with the Laboratory Design Guide were done primarily at the level of individual Strategies within the templates. Additional templates could be developed for other building types.

3. Tool reports are exported to Excel and Word formats so that users can have the full flexibility of those tools for reformatting or otherwise manipulating the content.
4. Efforts were made to begin distributing the Tool, with 400 copies given out at the Labs21 conference in October 2002.

Extensive interviews were conducted with prospective users to determine their needs and obtain feedback on user-interface mockups prepared by the LBNL team. The resulting tool is vastly simpler to navigate than the prior tool, yet more powerful. The User moves between only four primary “tabs”, most of which time is spent on the Design Intent Tab and its three sub-screens.

2.2.1. Test Case: U.C. Merced Laboratory Building

Working with several individuals from the UC Merced design team, we prepared a Design Intent Document for a planned Science & Engineering laboratory facility at the UC Merced campus. The 3-story facility is 166,000 square feet in size, has a mixture of laboratory types, and is intended for both teaching and research.

The extensive Basis of Design document was studied and key info transferred to the DIT. The resulting DID was 24 pages in length, and included over 27 Objectives, 106 Strategies, 48 Metrics, and 24 quantitative Targets (see Appendix III). The architect worked with the tool and found it very easy to learn the interface, move around in the tool, make modifications, etc. He noted that the tool fills an important “gap” in the current design documentation process. He also stated that he would have found the DIT valuable and would have used it if it had been available in the early stages of the UCM project.

In reviewing the preliminary DID, it was learned that a number of energy-efficiency features originally intended for the project had been dropped. This highlighted the importance of adding a module in future versions of the tool to record deletions, and, ideally, document the reasons for those decisions.

The architect pointed out that project managers would raise concerns over where the time would come from to do yet another “overhead” type effort that's not a deliverable requirement. He stated that the answer for the savvy client is to require design intent documentation as a deliverable, like a BOD, and for the design team to receive a sufficient fee to make it feasible.

2.3. Berkeley Fume Hood Development



Figure 2. Berkeley Hood under development

The original scope for the Berkeley Fume Hood Development involved an evaluation of the hood's performance during university demonstrations, identification of necessary design modifications, and commercialization plans for the hood. Since the university demonstrations at University of California, San Francisco (UCSF) and Montana State University were previously completed, the project approach was to summarize the observations and findings from these site demonstrations. A third demonstration planned for San Diego State University was not performed because a variance was not granted by CAL/OSHA (see discussion under Project Outcomes for the industrial demonstrations). The results of this evaluation are contained in an interim report entitled "The Berkeley Hood: Lessons Learned from Field Demonstrations", attached as Appendix V.

Following this evaluation, the Commission's Industrial program decided to pursue demonstrations of the Berkeley Hood in industrial installations. The project approach involved development of a wider (six-foot) hood, which is more commonly used in industrial settings. In prior demonstrations, LBNL's industrial partner, Labconco, provided standard fume hoods which LBNL then modified into "Berkeley Hoods." Unfortunately, Labconco declined to provide the hoods for the industrial demonstrations, but was willing to allow their design

drawings to be modified and provided to another manufacturer, Jamestown Metal Products. In addition, LBNL provided Jamestown with detailed modifications for the six-foot Berkeley hood. Jamestown agreed to deliver an operating hood that was ready for minimal development and tuning by LBNL.

In parallel, LBNL solicited interest in the industrial community to participate in the demonstration of the Berkeley hood. Several firms in various industries were eager to participate by offering their laboratories as demonstration sites. Each demonstration site falls under the jurisdiction of CAL/OSHA. CAL/OSHA requires laboratory-type hoods to maintain 100 ft./min through the hood's face. Since the Berkeley Hood does not rely on air velocity through the hood face at 100 FPM in order to provide containment, a variance was necessary from CAL/OSHA to allow each demonstration to proceed. Each of the industrial partners planned to submit a variance request to allow use of the Berkeley Hood in their facility. The industrial partners were expected to provide "in-kind" support for the demonstrations, which included their staff's time, installation, labor, and other related interface with their facility. In return, the hood would become their property upon completion of the demonstration.

Planning for the demonstrations involved preparation of a test plan that generally described the installation and testing that would be performed. The hood demonstration was to include operational testing to verify performance and other qualitative evaluations. Upon completion of the demonstrations, conclusions were planned to be summarized in a report. However as discussed in the Project Outcomes section, the approach required modification due to difficulties with the delivered prototype hood, and an insurmountable barrier (for the scope and timeframe of this project) imposed by the CAL/OSHA position on issuing variances. At the project critical review, the approach for the remainder of this project was revised to concentrate on actions to develop the larger, six-foot hood while continuing work to overcome institutional barriers. Overcoming institutional barriers involves working with ANSI to identify equivalent performance criteria to verify the Berkeley hood's containment. The progress leading to industrial demonstrations is described in more detail in the attached report, Appendix VI, "The Berkeley Hood: Progress towards Industrial Demonstrations".

2.4. High-performance Laboratories and Cleanrooms – a Technology Roadmap

Upon completion of the previous PIER project, a recommendation to prepare an industry developed roadmap to guide energy efficiency research and market transformation was included. Based upon previous research and benchmarking, an outline of roadmap topics was developed to illustrate the potential topics that could be included. With this outline as a starting point, topic descriptions were developed to begin defining the areas to target for efficiency improvement and a preliminary list of suggested research areas were identified. Other related needs identification efforts were also consulted such as Southern California Edison's "Large Customer Wants and Needs" study, and the SEMI "International Technology Roadmap".

Early in the development of the roadmap, a workshop was held at PG&E's Pacific Energy Center with the goal of further identifying research needs and industry barriers to implementing energy efficiency measures. The meeting had key industry participation representing the design community, high-tech building owners, energy engineers and consultants, and public goods program managers. The following companies provided input during this workshop:

- Intel Corporation
- Genentech Corporation
- Motorola
- Rumsey Engineers
- Jacobs Engineering
- Industrial Design Corporation (IDC)
- Sematech
- IBM
- Sempra Energy
- URS Corp.
- BKI
- Pacific Gas and Electric
- California Energy Commission
- Southern California Edison

The workshop provided a forum to identify areas of needed research and a portion of the time was spent identifying barriers to improved efficiency and possible means to overcome the barriers. Following the workshop, LBNL further developed the topic descriptions and suggested research areas into the first draft of the roadmap. While the roadmap was being developed, LBNL sought additional input from high-tech building design professionals and building operators. Additionally, research ideas were generated through informal collaborations with organizations such as Sematech, Laboratories for the 21st Century, and ASHRAE.

Once the first draft of the roadmap was developed, the topics were presented to industry representatives in several workshops. To help confirm that industry agreed with the research needs and to develop a priority for the topics, a survey was developed and reviewed by the Commission. It was then submitted to high-tech building professionals, including local industry partners, partners in the northwest, ASHRAE cleanroom committee members, and Sematech. This group provided input on priorities. Finally, LBNL attended a meeting of the Silicon Valley Manufacturers Group along with PIER managers. This group also enthusiastically endorsed the roadmap and expressed interest in rapidly moving forward.

Following the meeting with the Silicon Valley Manufacturers, the roadmap was finalized and submitted to the California Energy Commission.

3.0 Project Outcomes

3.1. Cleanroom Programming Guide

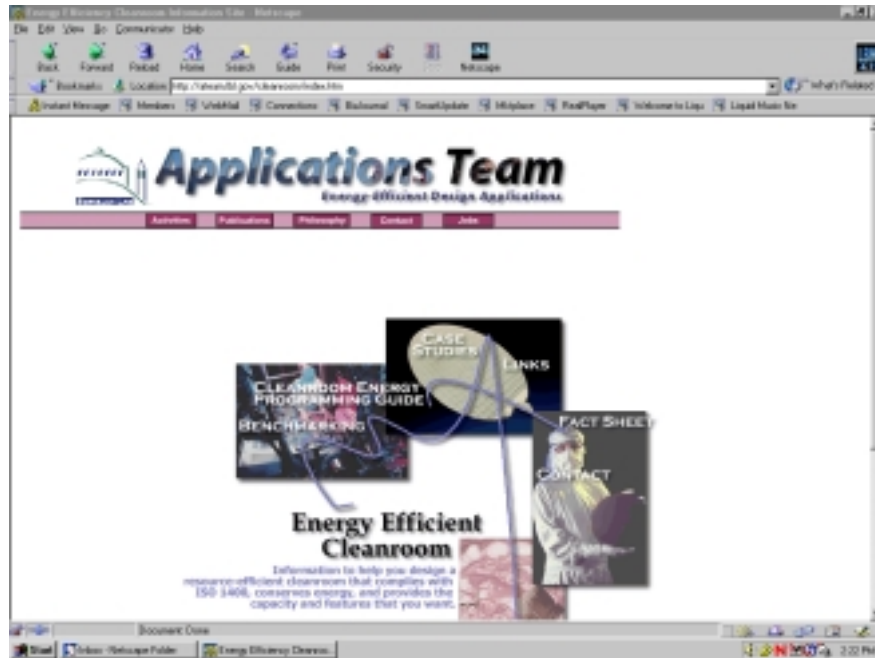


Figure 3. The Cleanroom Programming Guide online

The Cleanroom Programming Guide (LBNL Report 49223) was completed and is attached as Appendix I. It is available through the LBNL Cleanrooms website or directly through this link: <http://atteam.lbl.gov/cleanroom/guide/ProgrammingGuide-LBNL49223.pdf>

3.2. Design Intent Tool

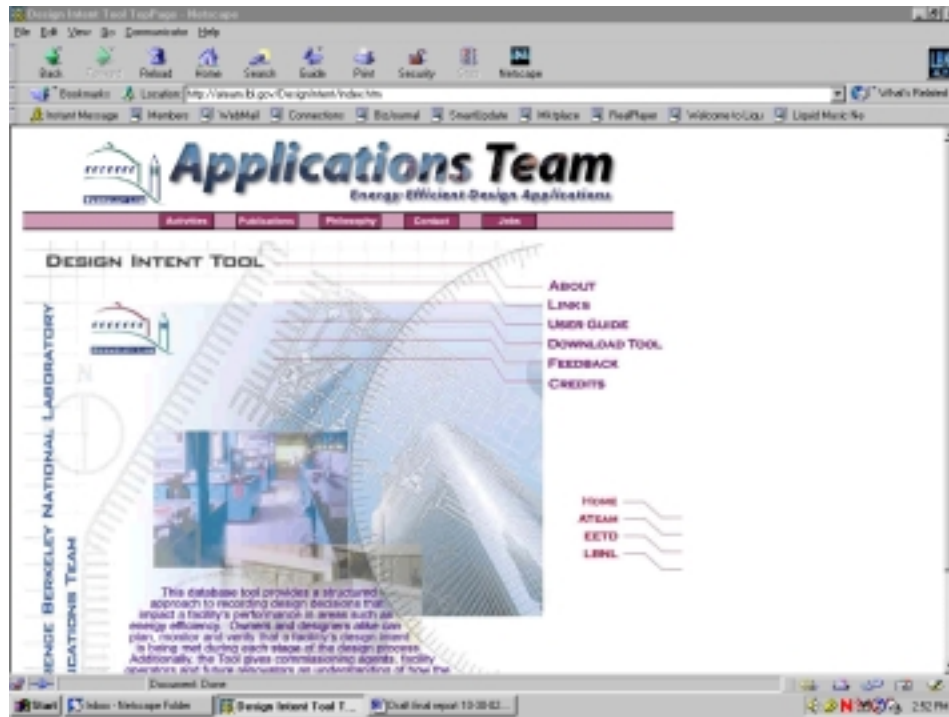


Figure 4. The Laboratory Design Intent Tool online

The Laboratory Design Intent tool was completed and demonstrated for trial use on a UC Merced Laboratory Project. An electronic copy of the tool is attached as Appendix II. It can also be downloaded from the LBNL website <http://ateam.lbl.gov/DesignIntent/index.htm>

The screenshot displays the Design Intent Tool 1.0 interface. A top menu bar includes options like 'Manage Projects', 'Manage Templates', 'Copy', 'Paste', 'Spelling...', and 'Exit'. Below this is a toolbar with buttons for 'Introduction', 'Manage Project Files', 'Manage Template Files', 'User Guide', 'Feedback', 'Help', and 'Web Home Page'. The main window shows a 'DESIGN INTENT TOOL' logo and a sidebar with 'Design Intent Overview', 'Project Name: LDM Project Test', 'Owner:', and 'Today's Date: 05-21-2002'. A 'Reports' button is visible in the top right. Callouts provide detailed information: 'Overview of the Design Intent Tool, Benefits, How to Use the Tool, etc.' points to the 'Introduction' button; 'Link to an electronic version of the User Guide' points to the 'User Guide' button; 'Program Help, Frequently Asked Questions, etc.' points to the 'Help' button; 'Link to website that supports the Design Intent Tool. Includes useful links, downloads of most recent version, etc. (Requires web connection.)' points to the 'Web Home Page' button; 'Manage Project & Template files. Allow user to create, open, and modify Project Files, as well as Template provided by the Tool without the Tool software at LDM, export Project Files for distribution to others, etc.' points to the 'Manage Project Files' button; 'Send an email to the Tool developer. (Requires web connection.)' points to the 'Feedback' button; 'Primary Tab: for navigation among the Data Entry screens' points to the 'Reports' button; and 'Fingerprints of Project File consistency to use, including project name, owner, and current date.' points to the project information area. A starburst graphic in the bottom right corner states 'Your data saved automatically as you go'.

Figure 5. Design Intent User Guide Screen Shot A

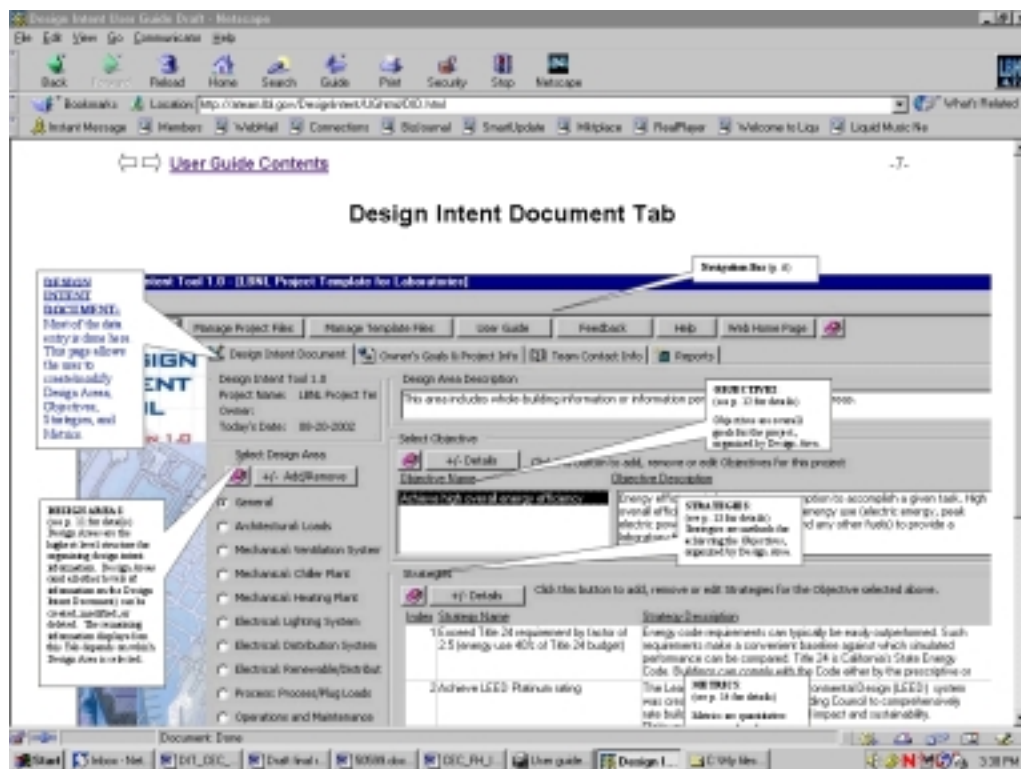


Figure 6. Design Intent User Guide Screen Shot B

3.3. Berkeley Fume Hood Development

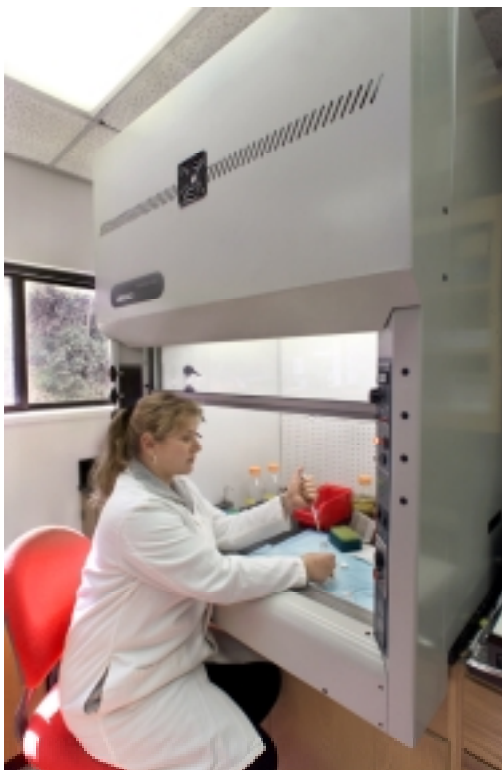


Figure 7. Berkeley Hood demonstration at UC San Francisco

For the original scope of work, an interim report, entitled “The Berkeley Hood: Lessons Learned from Field Demonstrations, 1995-2002” was prepared and is provided as Appendix V. This reports on the demonstrations of the Berkeley Hood in university settings and provides recommendations for further development.

Following the completion of this scope, additional scope was added to the project with the objective of demonstrating the Berkeley Hood performance in industrial settings. Unfortunately this activity encountered significant barriers that dictated re-scoping the project. The first challenge occurred when the industrial partner, fabricating a six-foot version of the Berkeley hood, failed to deliver the hood on schedule, and when provided, the hood did not function and required significant modifications. The second challenge, which became the ultimate barrier, was imposed by CAL/OSHA. Due to the fact that the Berkeley Hood utilizes a different containment mechanism than a standard fume hood, it is necessary to obtain a variance from CAL/OSHA to operate a Berkeley hood. The requested variance was not granted and, consequently, a lengthy process of appeal and justification to the CAL/OSHA standards board was undertaken. LBNL requested a PIER critical project review meeting where these barriers were discussed and a course of action was agreed upon. As a result, Berkeley Hood activities were then focused on overcoming the institutional barriers imposed by CAL/OSHA, and progress on developing an operational six-foot fume hood. A summary of the work in support of the industrial demonstrations is provided in the attached report “The Berkeley Hood – Progress towards Industrial Demonstrations” and is included as Appendix VI.

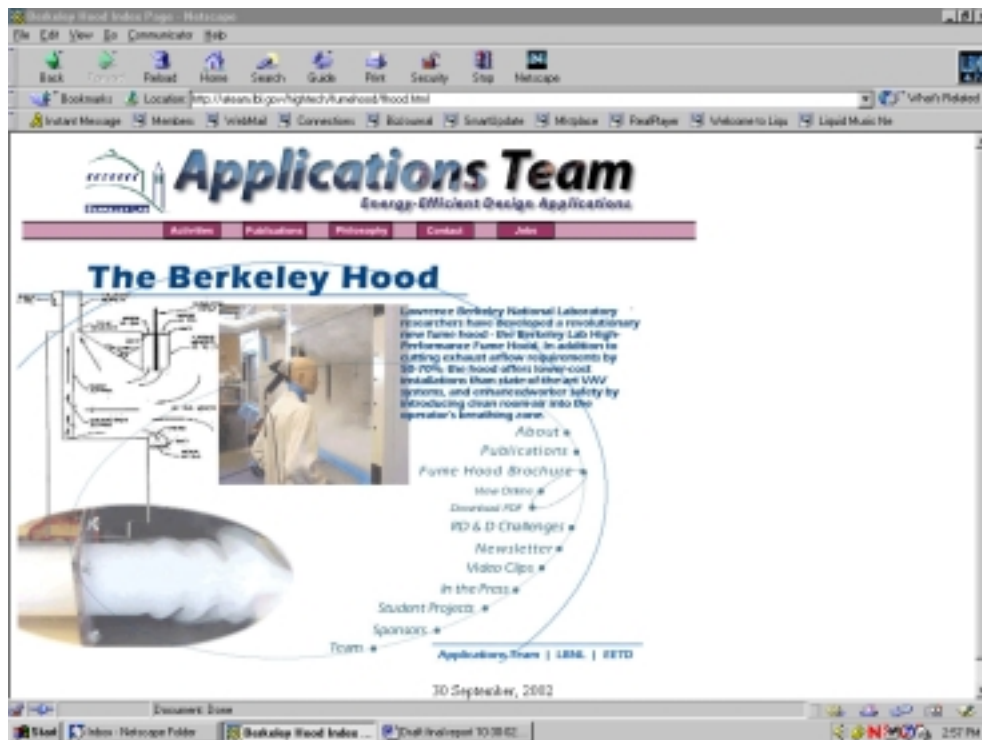


Figure 8. The Berkeley Fume Hood online

Information on the Berkeley Fume Hood is provided through this website
<http://ateam.lbl.gov/hightech/fumehood/fhood.html>

3.4. High-performance Laboratories and Cleanrooms – a Technology Roadmap

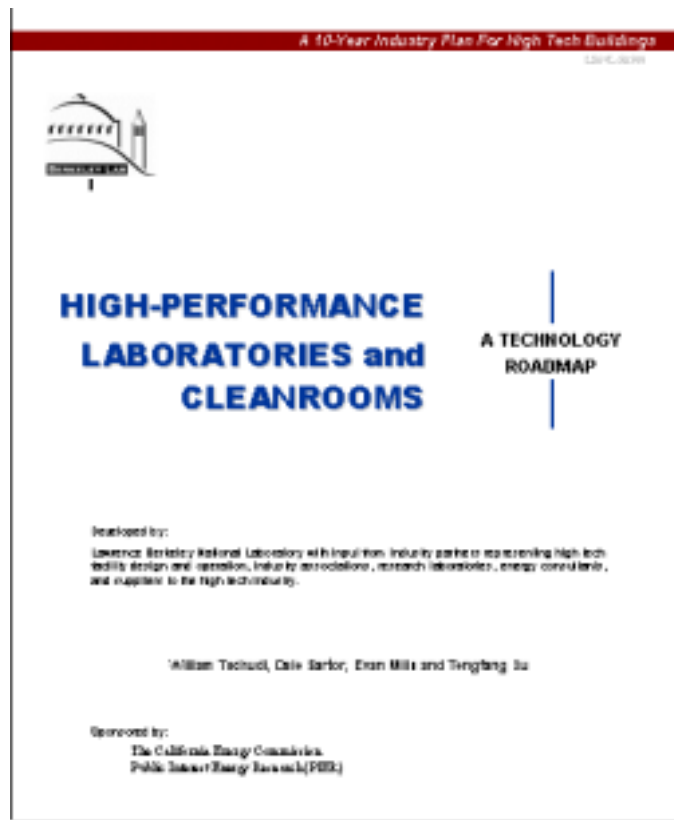


Figure 9. High-Performance Laboratories and Cleanrooms publication

The research roadmap entitled “High-Performance Laboratories and Cleanrooms – a Technology Roadmap” was developed through extensive interface with various industry experts in laboratory and cleanroom design and operation. The topics developed were validated and prioritized through several forums. A survey was developed to seek additional input and/or validate the topics identified. The survey form is attached as Appendix VIII. The results of the survey were used to prioritize the topics. This summary based upon industry feedback is included in the roadmap document following the roadmap activities. The completed roadmap is attached as Appendix VII.

*Summary and Priority
of
High-Tech Roadmap Issues*

	Priority 1 Highest	Priority 2	Priority 3	Priority 4 Lowest
4. Heating, Ventilating, and Air-Conditioning				
4.1 Optimize Airflow				
• Develop acoustic basis for recommended airflow				
• Develop alternatives for contaminant or environmental control				
• Develop methodology to optimize complex airflow				
4.2 Airflow Distribution Systems				
• Develop guidelines for design of low pressure drop systems				
• Develop protocols for optimizing complex duct systems				
• Develop air handler face velocity guidelines				
• Research low pressure drop concepts for fittings and components				
4.3 Optimize Chilled Water Systems				

Figure 10. Sample of priority listing of high-tech roadmap issues

4.0 Conclusions and Recommendations

4.1. Cleanroom Programming Guide

4.1.1. Conclusions

Throughout the development of the Cleanroom Programming Guide, an attempt was made to address as many energy impacting design and operational issues as practical. The philosophy was to provide a resource for building owners and designers to use during their typical programming sessions. A challenge in developing this information was in identifying only issues that could typically be addressed during programming and locked-in through early decisions - as opposed to those that would be decided through detailed design later in the project. Each project is different, so portions of the guide may apply on one project and have no bearing on another. In addition, there are undoubtedly issues included in the guide that may be better addressed during later phases of the design. The general guidance, however, would be applicable to aid decisions at any point in the project. A challenge is to keep the guide brief enough that it will be read. Workshop participants suggested including a checklist (which is now included) to enable the programming team to quickly go through issues and then if more detail is desired, go to the body of the guide. A possible future enhancement would be to organize the guide into a hierarchical structure that begins with a checklist and then electronically links to deeper levels of detail and reference material similar to the existing design guide for energy efficient laboratories (<http://ateam.lbl.gov/Design-Guide/index.htm>)

The guide addresses topics generically in a wide range of applications and industries. Some of the industry partners would have liked an industry specific guide developed (i.e. semiconductor, or biotechnology, etc. specific to their industry). Most feedback however was positive with industry expressing the need for more guidance and ideas on methods to improve efficiency of cleanrooms.

It is intended that this resource would stimulate discussion and thought for a key design parameter – namely energy use – that up until now, has not been considered with the same rigor that other design criteria receive when planning a new cleanroom project. Industry paradigms had branded energy as being uncontrollable, or unimportant since energy is a relatively small percentage of the operating cost. As the guide was developed, it was evident that there was a need for better information including benchmarks and best practices. There were champions ready to implement new ideas but in some areas, best practices are not readily identified. A positive outcome is that the guide encourages owners and designers to have a constructive dialogue on energy issues. This is likely to lead to setting higher performance goals, and decisions based on life-cycle cost analysis, as well as increased interest in developing more efficient solutions.

4.1.2. Commercialization Potential

This guide was not originally intended to be commercialized in the sense of developing it as a product for sale, although organizations such as ASHRAE, or SEMI could be interested in making it available for a fee. Market transformation strategy would be better served by providing the guide through public information, and providing outreach to the industries that depend upon cleanrooms. Demonstrations on real projects, workshops, and distribution through targeted industry associations could reach a large percentage of the professionals in this market.

4.1.3. Recommendations

Trial use of the guide is necessary now to determine how it will be used and to identify enhancements to ensure its use. To date, there have been no full trials of the guide, however the concepts presented in the guide were used to make suggestions in three design Charrettes. Two of the charrettes were for semiconductor facility projects in the northwest, and one was at Sandia National Laboratory in Albuquerque, NM. At each of these programming sessions, some of the key concepts presented in the guide were introduced to the programming teams. Based upon the reactions from the design teams the following observations and recommendations are made:

1. Many details in addition to energy are decided at the programming phase. The programming team will likely focus on a only a few key energy issues.
2. Recommendation: Through trial use, prioritize the topics and investigate ways to streamline the guide in a hierarchical fashion. See if separate programming sessions to address only energy issues are practical.
3. Programming team decisions are often schedule driven. Analysis to evaluate energy options is rarely done. Designs that have worked in the past (although inefficiently) are preferred over new concepts.
4. Recommendation: Obtain more robust energy benchmark data to illustrate what others have achieved. Document best practices and provide references to them through the guide.
5. Participants were encouraged to establish efficiency design goals for their projects. There was reluctance to this for two reasons: First, many areas have no benchmarks or other basis to establish targets. Secondly, with current design practices, there are liability issues if designers do not provide adequately sized systems. This fact, coupled with the uncertainties in process loads, often causes designers to oversize systems leading to inefficient oversized systems.
6. Recommendation: Obtain additional benchmark information. Develop incentive strategies and programs that owners can employ to strike a balance between liability driven design and energy efficient design.
7. Traditional programming sessions involve most key stakeholders, however, higher management level participation is necessary to balance capital/operating cost conflicts and long/short term impacts. Some decisions were made based upon expediency (schedule driven), some made on first cost (no life cycle cost consideration or no budget to evaluate alternatives), and some were made based upon personal preference (with no evaluation). Management involvement may have overcome some of these issues.
8. Recommendation: Attempt to involve senior management in trial use of the programming guide. Ideally, the senior manager would be the owner's champion investigating use of the guide.

Following trial use of the guide in several projects, enhancements should be made if necessary, and an assessment of how the guide could best be deployed to, and used by, the targeted industry professionals should be made. Issues to be considered include the following: What participants are best to consider the issues in the guide? What level of management involvement is appropriate? How would the guide better relate to management? How are programming sessions best structured to address energy issues?

Recommended activities ideally would be co-funded by the Commission and the Northwest Energy Efficiency Alliance and involve projects from both locations. Workshops or other market transformation activities should be provided at locations where there are high concentration of cleanroom facilities, such as the "Silicon Valley" area, San Diego, Los Angeles, Santa Barbara, Portland, and Seattle. The workshops could be provided in conjunction with other Commission or public utility programs, industry association meetings, or as stand-alone events.

4.1.4. Benefits to California

The guide provides a needed resource to the high-tech community that is so important to California's economy. Although it is difficult to quantify savings potential - this will depend on the measures undertaken by the individual programming teams and overcoming barriers - prior investigations suggest that 10-20% savings can be readily obtained through better design. LBNL's previous benchmark work illustrates that even greater savings can be obtained by simply adopting the best current practices. More work needs to be done to "flush out" best practices but some practices are clear winners. Immediate benefits are expected, once owners and designers begin discussing energy as a design requirement rather than an uncontrollable cost. Setting aggressive but achievable energy goals at the onset of a project can lead to large savings with little or no impact on first cost. Utilizing life cycle cost evaluations rather than strictly first cost can also add significant energy savings. Since these buildings are typically 24x7 operating facilities, lowering demand will have even greater benefits than commercial buildings and some industries. Lowering demand will also result in more reliability for these industries as the electrical infrastructure adapts for growth.

4.2. Design Intent Tool

4.2.1. Conclusions

The tool was considerably improved during the recent period of work, with extensive cross-linkages with the Laboratory Design Guide, and a new User Guide developed. Based on our initial market research and subsequent user feedback, there is clearly a desire to have the tool ported to a web-based platform so that it would function more effectively as a collaborative tool.

4.2.2. Commercialization Potential

The Design Intent Tool fills an important void, complementing existing building design software.

Preliminary contacts were made with a number of private-sector developers of collaborative software tools. The notion of integrating the DIT into existing collaborative tools could be explored, but there would probably remain value in having a stand-alone tool.

In order for a tool such as the DIT to be used, there needs to be customer-driven demand for the service. This requires that project developers become aware of the tool and its benefits and provide the mandate and resources for their design teams to utilize it.

4.2.3. Recommendations

Based on user feedback, we have identified the following additional recommended development for the Tool:

Technology Transfer

- Promote availability of tool through bulletin boards, trade literature, conferences, workshops, and training.

Improved Usability

- Shift platform to Internet (retaining database back-end)
 - Facilitates intended collaborative use and information sharing
 - Requires “permissions” module (read, write, etc.)
 - Allow for attachment of additional documents
- Allow users to add/subtract/modify the Help (“?”) buttons and their content
- Create links to Benchmarking information (to support selection of Target values in Metrics)
- Create “Undo” button to reverse data-entry errors
- Offer tool with a runtime version of Access2000 (for users who have an older version of Access and prefer not to purchase the upgrade).

Interface Improvements

- “Status” indicator for entries, e.g. “proposed”, “accepted”. Allow reports to be made for pending items to facilitate group discussion and decision-making
- Make “Contact Info” into one large field (facilitates cutting and pasting from other documents)
- More roll-overs and context-sensitive help
- Templates
 - Make improvements to “Laboratories” template
 - Make improvements to the “LEED” template
 - Add new templates, e.g. cleanrooms
- Add Tab with “Rejected Measures”, person rejecting, reasons for rejection, etc.
- Allow for sub-strategies, sub-Objectives, and sub-metrics
- Allow more flexibility in hierarchy, e.g. metrics can be linked to Objectives or Strategies.
- Elevate Assessment Record to the level of a Tab
- Reports
 - To make the reports more compact/concise, suppress printing of field names with no value.
 - Include associated Help Links in the reports
 - Improve report formatting

4.3. Berkeley Fume Hood Development

4.3.1. Conclusions

The technology utilized in the Berkeley Fume Hood can provide significant energy savings along with improved worker safety. In California, the energy consumed by a standard fume hood is approximately equal to that of three houses. Saving up to 60% of this energy is a promising goal for the Berkeley hood. Continuing development and testing of the fume hood confirms the viability of the technology in spite of the roadblocks that this portion of the project encountered. Although the industrial demonstrations could not be accomplished, the steps being taken to convince CAL/OSHA of the hood's safety performance are valuable and an appropriate roll for California's public interest research. It is unlikely that hood manufacturers would attempt to challenge the long-standing "rule of thumb" that CAL/OSHA embraces. To satisfy CAL/OSHA, an equivalent standard of performance verification, such as tracer gas testing, will likely be required. Demonstrating safe containment to CAL/OSHA may actually accelerate the commercialization by providing convincing evidence of safety to other jurisdictions, potential manufacturers, and end users. This provides needed assurance that the hood will be safe along with producing energy savings.

4.3.2. Commercialization Potential

Fume hood manufacturers continue to be excited and supportive of developing this technology. The major barrier to commercialization progress has been the reluctance of CAL/OSHA to allow use of the Berkeley Hood's containment technology in lieu of relying on hood face velocity for containment. Once an alternate criterion is accepted and demonstrated in industrial settings, commercialization will be accelerated.

4.3.3. Recommendations

Follow-on development activities are proposed with the objective of resolving the CAL/OSHA barrier, completing the scale up to a six-foot hood, and demonstrations in industrial facilities. The next steps should include side-by-side testing with a conventional fume hood, use of Computational Fluid Dynamics (CFD) analysis to aid design and verify performance, and demonstrations in three to five facilities in various industries. Future development to establish a retrofit design using the Berkeley Hood technology should also be pursued.

4.3.4. Benefits to California

Estimated savings in California through use of the Berkeley Hood are approximately \$162 million/year with a peak load saving of 215 MW.

4.4. High-performance Laboratories and Cleanrooms – a Technology Roadmap

4.4.1. Conclusions

A change has been occurring in how California's high-tech industries view energy. The California Energy crisis and the downturn in the high-tech sector have both led to increased interest in saving energy. While the energy crisis was occurring, manufacturers began to collaborate more and more. The Silicon Valley Manufacturers Group, for example, elevated energy concerns to a high level seeking political relief as well as efficiency improvements. Companies became eager to participate in benchmarking and were actively looking for

efficiency opportunities. The group saw benefits in electrical distribution system reliability if they could all become more efficient and, increasing energy costs were emphasizing the need for savings. Later, as the high-tech market declined, interest level remained high because improving bottom line savings was essential. As a result, the industry definitely supported the research efforts related to high-tech buildings and it was relatively easy to solicit their input. As the roadmap developed, LBNL's utility sponsored cleanroom benchmarking was completed. The limited benchmark results helped to focus discussion on the most energy intensive systems and their research opportunities/needs.

4.4.2. Commercialization Potential

Although the roadmap addresses needed research, primarily with a public goods perspective, there are a number of topics where industry could take the lead, given encouragement or where a clear market potential exists. For example, more efficient HVAC equipment could be developed by manufacturers given greater market pull. Owners and designers need to be demanding improvements and the market will respond.

4.4.3. Recommendations

A multi-year research agenda is presented in the roadmap. California's PIER program should proceed with the high priority tasks identified by industry as the most beneficial to California companies. Collaboration with other industry efforts, such as Sematech, ASHRAE, IEST, etc. should continue to enable as much of the roadmap to be realized as possible. To achieve the full potential in energy savings, a whole building approach is needed. Individual activities will achieve a level of improvement but attacking the overall opportunity will yield large benefits to industry and the state's ability to provide adequate energy supply to meet demand. A multi-year program that provides research into the full range of topics identified in the roadmap (beyond the first priority items) will lead to a 40-50% reduction in energy use.

The high-tech industries are continually in change. Process technologies change rapidly and have a profound impact on the facilities. Consequently, the roadmap topics and their priority should be reviewed periodically. The roadmap should be considered a living document with changes in priority and technological emphasis made as the market needs change.

4.4.4. Benefits to California

The High Performance Laboratories and Cleanrooms technology roadmap provides the PIER program with much needed understanding of industry views of needed research and its priority. The Commission's Industrial Program will be able to utilize the roadmap to plan a strategy to aggressively make improvements in this critical market sector. The roadmap will also facilitate collaborations with other energy research and industry organizations thereby leveraging California's efforts.

5.0 References

Bell, G., D. Sartr, and E. Mills. "The Berkeley Hood - Lessons Learned from Field Demonstrations - Interim Report for the California Energy Commission", Lawrence Berkeley National Laboratory, January 2002

Tschudi, W.; D. Sartor; T. Xu, 2001 "An Energy Efficiency Guide for use in Cleanroom Programming" Lawrence Berkeley National Laboratory report No. 49223

William, P., et al. 1987. Problem Seeking: An Architectural Programming Primer 3rd edition (October 1987), American Institute of Architects; ISBN: 0913962872.

Appendix I

**“An Energy Efficiency Guide for use in Cleanroom Programming”
Lawrence Berkeley National Laboratory report No. 49223**

Appendix II

“Design Intent Tool: User Guide”

Appendix III

“Design Intent Tool Case Study: U.C. Merced”

Appendix IV

“Design Intent Tool Website”

Appendix V

“The Berkeley Hood: Lessons Learned from Field Demonstrations”

Appendix VI

“Final Summary Compilation” (four documents)

Appendix VII

“High-Performance Laboratories and Cleanrooms – a Technology Roadmap,” Lawrence Berkeley National Laboratory Report No. 50599

Appendix VIII

**“Energy efficiency Roadmap for high-tech buildings Laboratory and
Cleanroom Industry Survey”**